SYSTEM AND METHOD FOR ANALYZING ACTIVITY OF A BODY

The present invention claims priority to United States Provisional Application Serial No. 60/265,521 filed on January 31, 2001 entitled "SYSTEM AND METHOD FOR DETECTING AN ACCELERATION OF A BODY".

RELATED APPLICATIONS

This patent application is a continuation in part of co-pending United States Patent Application No. 09/909,404 filed July 19, 2001 by Lehrman et al. entitled "System and Method for Detecting Motion of a Body," which is a continuation in part of co-pending United States Patent Application No. 09/396,991 filed September 15, 1999 by Lehrman et al. entitled "Systems For Evaluating Movement of A Body and Methods of Operating The Same" that issued on October 23, 2001 as United States Patent No. 6,307,481. United States Patent Application Nos. 09/909,404 and 09/396,991 are both assigned to the assignee of the present invention. The disclosures in United States Patent Application Nos. 09/909,404 and 09/396,991 are hereby incorporated by reference in the present application as if fully set forth herein.

TECHNICAL FIELD OF THE INVENTION

The present invention relates generally to means for analyzing activity of a body relative to an environment, and, more particularly, relates to systems and methods of operation for evaluating movement of a body to analyze body motion, such as falls, irregular movement, including inactivity, etc.

BACKGROUND OF THE INVENTION

Methods for determining specific movements of a body that use a variety of devices, apparatus and systems are, generally speaking, known. The term "body" is defined broadly hereafter and includes both organic and inorganic objects.

In point of fact, many methods are known for sensing body activity, including both movement and non-movement (*i.e.*, sensed dynamic accelerations, including cessation of movement), as well as, for sensing body movement over time, which is commonly used to determine comparative levels of activity of a monitored body (*See*, United States Patent Nos. 4,110,741, 4,292,630, 5,045,839, and 5,523,742). These methodologies, however, merely report various levels of body activity, and, simply stated, fail to recognize possible causes for any increased or decreased level of body activity.

In contrast, other methodologies have developed over time for the detection of falls (*See also*, United States Patent Nos. 4,829,285, 5,477,211, 5,554,975, and 5,751,214). These methodologies are largely based upon the utilization of one or more mechanical switches (*e.g.*, mercury switches) that determine

5   when a body has attained a horizontal position. These methods however fail to discern "normal," or acceptable, changes in levels of body activity. Stated another way, the foregoing fall detection methodologies provide no position change analysis and, therefore, cannot determine whether a change in position, once

10   attained, is acceptable or unacceptable.

For instance, in veterinary applications, it is well known that horses sleep while standing and that their breathing is less effectively if they are lying down, particularly if on a side. If a high value mare in foal lies down for a period of time (*i.e.*, is

15   inactive), there is an appreciable economic risk. Contemporary systems and methodologies do not provide activity monitors that "warn" or "alarm" that the absence of movement within a specific environment is dangerous.

As a further example, if a body under consideration was an

20   extraction pump and the environment were either a sump near a subway station, in addition to monitoring for normal operation, which is very episodic and activated by accumulating water, the

pump should be monitored for inactivity over some period of time as indicia that the pump may be malfunctioning and jeopardizing the nearby subway tunnel. Warning of the absence of activity of machinery, depending upon the environment, can have significant safety, economic, and like effect.

5   Various training methods have been conceived for sensing relative tilt of a body (*See*, United States Patent Nos. 5,300,921 and 5,430,435), and some such methodologies have employed two-axis accelerometers. The output of these devices, however, have reported only static acceleration of the body (*i.e.*, the position 10 of a body relative to earth within broad limits). It should be appreciated that static acceleration, or gravity, is not the same as a lack of dynamic acceleration (*i.e.*, vibration, body movement, and the like), but is instead a gauge of position. While accelerometers that measure both static and dynamic 15 acceleration are known, their primary use has heretofore been substantially confined to applications directed to measuring one or the other, but not both. For instance, the absence of activity/movement for a period of time for a snowmobile or other all-terrain vehicle in the field may signal an equipment breakdown 20 placing the safety of the user at risk.

It may be seen that the various conventional detectors fall into one of two varieties, those that gauge movement of the body

and those that gauge a body's position by various means, with neither type capable of analyzing body activity to determine whether the same is normal or abnormal; and if abnormal, whether such activity (including inactivity) is so abnormal to be beyond tolerance, for instance, to be damaging,

5   destructive, crippling, harmful, injurious, or otherwise alarming or, possibly, distressing to the body.

None of the methodologies heretofore known have provided a suitable means to evaluate body activity over time and to determine whether such activity is tolerable. Further improvement could thus

10   be utilized.

SUMMARY OF THE INVENTION

To address the above-introduced deficiencies of the prior art, the present invention introduces systems, as well as methods of operating such systems, for evaluating body activity relative to an environment. For the purposes hereof, the term "body" is defined broadly, meaning any organic or inorganic object whose activity (*e.g.*, movement, position, etc.) may suitably be evaluated relative to its environment in accordance with the principles hereof; and where the term "environment" is defined broadly as the conditions and the influences that determine the behavior of the physical system in which the body is located.

An advantageous embodiment of a system that evaluates body activity relative to an environment in accordance herewith includes a processor that is associated with a sensor. In operation, the sensor is associated with the body and operates to repeatedly sense dynamic and static accelerative phenomena of the body. The processor processes the sensed dynamic and static accelerative phenomena as a function of at least one accelerative event characteristic and an environmental representation to thereby determine whether the evaluated body activity is within environmental tolerance. The processor operates to monitor both activity and inactivity relative to the environmental representation. The processor also preferably generates state

indicia while processing the sensed accelerative phenomena, which represents the state of the body within the environment over time.

For the purposes hereof, the term "sensor" is defined broadly, meaning a device that senses one or more absolute values, changes in value, or some combination of the same, of at least the sensed accelerative phenomena. According to an advantageous embodiment, described in detail hereafter, the sensor may be a plural-axis sensor that senses accelerative phenomena and generates an output signal to the processor indicative of measurements of both dynamic and static acceleration of the body in plural axes. The phrase "environmental representation," as used herein, is defined broadly as any mathematical or other suitable depiction, delineation, model or like measured description of the environment associated with the body.

According to this embodiment, the processor receives and processes the output signal. The processor is preferably programmed to distinguish between normal and abnormal accelerative events, and, when an abnormal event is identified, to indicate whether the abnormal event is tolerable, or within tolerance. The processor accordingly operates to monitor both activity and inactivity relative to the environmental representation.

According to a related embodiment, the processor can determine when the evaluated body activity is relatively small to inactive as a function of the environmental representation. If the body activity level remains relatively small to inactive for a threshold time period, then the processor is operable to generate an alarm signal. In an advantageous implementation, as the time period approaches a threshold, the processor is also operable to generate a warning signal. Likewise, if the processor determines a relative increase in body activity, it is also operable to restart (*i.e.*, reset) the time period.

In further embodiments, the processor may be programmed to distinguish other physical characteristics, including temperature, pressure, force, sound, light, relative position, and the like. It should be noted that the relevant environment may be statically or dynamically represented. The sophistication of any such representation may be as complex or as uncomplicated as needed by a given application (*e.g.*, disability, injury, infirmity, relative position, or other organic assistance monitoring; cargo or other transport monitoring; military, paramilitary, or other tactical maneuver monitoring; etc.). It should further be noted that any representation may initially be set to, or reset to, a default, including, for instance, a physically empty space, or vacuum.

Regardless, the principles of the advantageous exemplary

embodiment discussed heretofore need at least one accelerative event characteristic to be represented to enable the processor to determine whether the evaluated body activity is within environmental tolerance, which is again advantageously based upon both dynamic and static acceleration measurements.

5   According to a related advantageous embodiment, the system may be associated with other components or sensing systems. For instance, in an assistance monitoring application, the sensor may repeatedly sense dynamic and static acceleration of the body in the plural axes and generate output signals indicative of the 10 measurements. The processor continuously processes the output signals to distinguish between selected accelerative and non-selected accelerative events (described in detail hereafter) based upon both the dynamic and the static acceleration of the body, and generates state indicia, including tolerance indicia, 15 that is communicated to a monitoring controller.

In an advantageous embodiment, the system processes accumulated data for purposes of determining and selectively signaling if a select (e.g., static, dynamic, variable, etc.) amount of activity has not occur over a select (e.g., static, 20 dynamic, variable, etc.) time period. The system may suitably be arranged to signal if (a) relatively low to no activity occurs over a given time period indicating that the associated body may have

suffered a unacceptable event (*e.g.*, a patient suffered a stroke in bed, a prisoner failed to comply with wearing a monitoring system, etc.), or (b) a select level of activity is not occurring over a given time period indicating that the associated body may fail to meet a defined level of activity (*e.g.*, a prescribed regimen of

5   activity required to rehabilitate an injury or to maintain health).

According to another embodiment, the system may suitably be arranged to transmit (*e.g.*, continuously, periodically, etc.) to a remote monitor that cooperates with the processor to (a) make notice/alarm-type decisions, or (b) capture "counts" and other

10   suitable statistics for subsequent evaluation of trends in activity levels (*e.g.*, to identify possible changes in body's level of activity; in the case of equipment, possibly to increase efficiency). Regardless of the purpose, tolerance indicia may suitably to communicated to the monitoring controller for record

15   keeping/statistical purposes, as well as to provide "live" monitoring of the individual subscriber.

Communication between the processor and the controller may be by a wireless network, a wired network, or some suitable combination of the same, and may include the Internet.

20   Preferably, the system generates an alert whenever the monitored subscriber is in "jeopardy," as determined by the system, such as in response to a debilitating fall by the subscriber. In a

further embodiment, the processor is operable to repeatedly generate "heartbeat" indicia that indicates that the system is in an operable state, whereby absence of the same informs the monitoring controller that some other part of the system is malfunctioning.

5   The foregoing has outlined rather broadly the features and technical advantages of the present invention so that those skilled in the art may better understand the DETAILED DESCRIPTION OF THE INVENTION that follows. Additional features and advantages of the invention will be described hereinafter that form the subject

10   of the claims of the invention. Those skilled in the art should appreciate that they may readily use the conception and specific embodiments disclosed as a basis for modifying or designing other structures for carrying out the same purposes of the present invention. Those skilled in the art should also realize that

15   such equivalent constructions do not depart from the spirit and scope of the invention in its broadest form.

Before undertaking the DETAILED DESCRIPTION OF THE INVENTION, it may be advantageous to set forth definitions of certain words and phrases used throughout this patent document: the terms "include"

20   and "comprise," as well as derivatives thereof, mean inclusion without limitation; the term "or," is inclusive, meaning and/or; the phrases "associated with" and "associated therewith," as well

as derivatives thereof, and the term "associable" may mean to include, be included within, interconnect with, contain, be contained within, connect to or with, couple to or with, be communicable with, cooperate with, interleave, juxtapose, be proximate to, be bound to or with, have, have a property of, or

5   the like; and the terms "controller" and "processor" mean any device, system or part thereof that controls at least one operation, such a device may be implemented in hardware, firmware or software, or some suitable combination of at least two of the same. It should be noted that the functionality associated with

10   any particular controller/processor may be centralized or distributed, whether locally or remotely. Definitions for certain words and phrases are provided throughout this patent document, those of ordinary skill in the art should understand that in many, if not most instances, such definitions apply to

15   prior, as well as future uses of such defined words and phrases.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, wherein like numbers designate like objects, and in which:

FIGURE 1 illustrates an isometric view of an exemplary embodiment of a system that evaluates body activity in accordance with the principles of the present invention;

FIGURE 2 illustrates a block diagram of the exemplary system set forth with respect to FIGURE 1;

FIGURES 3A to 3D illustrate exemplary strip chart records of output of the sensor introduced in FIGURES 1 and 2 taken during illustrative situations;

FIGURE 4 illustrates an operational flow diagram of an exemplary method of programming a processor in accordance with a fall detection application of the principles of the present invention;

FIGURE 5 illustrates a functional block diagram of an alternate sensing system that may suitably be associated with the processor of the present invention;

FIGURE 6 illustrates a perspective view of an exemplary remote receiver unit of the system of this invention;

FIGURE 7 illustrates a functional block diagram of the exemplary receiver unit of FIGURE 6;

FIGURE 8 illustrates an exemplary wireless network that is associated via a wired network, such as the Internet, to a remote monitoring controller according to one embodiment of the present invention; and

FIGURE 9 illustrates an exemplary embodiment of the system of the present invention for evaluating body movement with a plurality of acceleration measuring devices;

FIGURE 10 illustrates the coordinate relationships between a three dimensional Cartesian coordinate system and a three dimensional spherical polar coordinate system;

FIGURE 11 illustrates the orientation of a first plural axis accelerometer in an x-y plane of a three dimensional Cartesian coordinate system and the orientation of a second plural axis accelerometer in a y-z plane of the same Cartesian coordinate system;

FIGURE 12 illustrates an exemplary embodiment of the system of the present invention for evaluating body activity comprising two plural axis accelerometer sensors coupled to a controller;

FIGURE 13 illustrates a flow diagram showing a first portion of an advantageous embodiment of the method of the present invention;

FIGURE 14 illustrates a flow diagram showing a second portion of an advantageous embodiment of the method of the present

5   invention; and

FIGURE 15 illustrates a flow diagram showing a third portion of an alternate advantageous embodiment of the method of the present invention.

DESCRIPTION OF THE INVENTION

FIGURES 1 through 15, discussed below, and the various embodiments used to describe the principles of the present invention in this patent document are by way of illustration only and should not be construed in any way to limit the scope of the invention. Those skilled in the art will understand that the principles of the present invention may be implemented in any suitably arranged system for detecting the motion of a body.

FIGURE 1 illustrates an isometric view of an exemplary embodiment of a system (generally designated 11) that evaluates body activity in accordance with the principles of the present invention, and more particularly that measures and distinguishes selected accelerative events of a body (not shown). As used in this disclosure, the phrases "accelerative events" or "accelerative phenomena" are defined as occurrences of change in velocity of the body (or acceleration), whether in magnitude, direction or both, and including cessation of activity or inactivity.

System 11 includes circuit boards 13 and 15 (connected boards at right angles to one another) that are associated with a housing (generally designated 17) utilizing known mounting techniques. Exemplary housing 17 (and system 11, for that matter), when assembled, is approximately one centimeter thick

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and is approximately five centimeters across in any direction.

Housing 17 may comprise, for example, exemplary housing halves 19 and 21 that encase boards 13 and 15, although those skilled in the art will understand that any configuration suitable for a particular implementation of the invention may be
5   arranged.

Exemplary rear half 21 is provided with a clip 23 for associating system 11 with the body (e.g., people, animals, objects of various sorts, etc.). Exemplary clip 23 is shown as a mechanical spring-type clip, but could be any known attachment
10   device or system, including either mechanical or chemical attachment systems, or any other suitable means for associating system 11 with the body.

System 11 includes a processor (shown in FIGURE 2) and a sensor 25. Exemplary sensor 25 operates to sense accelerative
15   phenomena of the body, and is mounted on circuit board 13 with *x* and *y* axes, 27 and 29, respectively, oriented thereat (though other orientations could be utilized). Sensor 25 is illustratively shown as a plural-axis (dual shown) acceleration measuring device suitably mounted on a single monolithic integrated
20   circuit (one conventional sensor is an accelerometer available from ANALOG DEVICES, INC., located at One Technology Way, Norwood, Massachusetts, United States of America, namely,

Model No. ADXL202). Sensor 25 includes polysilicon surface-micromachined sensor layer 31 built on top of silicon wafer 33. Polysilicon springs 35 resiliently suspend sensor layer 31 over the surface of wafer 33 providing resistance against acceleration forces. Deflection of the sensor layer is measured using a

5   differential capacitor formed by independent fixed and central plates, the fixed plates driven by one hundred eighty degrees (180˚) out of phase square waves having amplitude proportional to acceleration. Signal outputs from each axis of sensor 25 are conditioned (*i.e.*, phase sensitive demodulation and low pass

10   filtering) and presented at analog output nodes. While not utilized in the primary advantageous embodiment of this invention, the ANALOG DEVICES' accelerometer is operable to convert the analog signals to duty cycle modulated ("DCM") signals at a DCM stage providing digital output signals capable of being directly counted

15   at a processor.

While techniques for reconstructing analog signals from the digital output signals may suitably be utilized (*e.g.*, passing the duty cycle signals though an RC filter), thereby allowing use of the digital signal output of a sensor of system 11 hereof, use

20   of the analog signal outputs has been found advantageous due to the increased bandwidth availability (0.01 Hz to 5 kHz, adjustable at capacitors at the output nodes to bandlimit the

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nodes implementing low-pass filtering for antialiasing and noise reduction), and the measuring sensitivity that may be attained. A typical noise floor of five hundred micro "g" per Hertz (500 x 10^{-6} "g"/Hz) is achieved, thereby allowing signals below five milli "g" (5 x 10^{-3} "g") to be resolved for bandwidths below

5   60 Hz. The value "g" is the acceleration of gravity at the surface of the earth (32 feet/sec² or 9.8 m/sec²).

According to the illustrated embodiment, sensor 25 generates analog output voltage signals corresponding to measurements in the *x* and *y* axes, which include both an alternating current (*ac*)

10   voltage component proportional to *G* forces (*i.e.*, dynamic acceleration component related to vibrations of sensor layer 31) and a direct current (dc) voltage component proportional to an angle relative to earth (*i.e.*, static acceleration component related to gravity). This open loop acceleration measurement

15   architecture, capable of measuring both static and dynamic acceleration, can thus be utilized to determine position of a body by measuring both the *x* and *y* output voltages simultaneously, as well as measure forces of impact experienced by a body. This information comprises state indicia, and

20   utilizing both signal components from both outputs, the sensed accelerative phenomena of the body may subsequently be processed to distinguish a variety of accelerative phenomena and,

ultimately, to selectively act based on the distinctions, as is described in detail hereafter to determine whether the evaluated body activity is normal or abnormal, and, if abnormal, whether the same is within tolerance.

It is noted that the foregoing embodiment has been introduced for illustrative purposes only. In alternate embodiments, any sensor that is capable of sensing accelerative phenomena relative to a body may be used in lieu of, or even in conjunction with, sensor 25. Further, alternate orientations of sensor 25 may be used for different applications. Stated differently, system 11 is operable to evaluate body activity relative to an environment and, in operation, sensor 25 (regardless of configuration or select functional aspects) is associated with the body and operates to repeatedly sense dynamic and static accelerative phenomena of the body. The system, preferably using a suitably arranged processor, processes the sensed phenomena as a function of at least one accelerative event characteristic and a representation of the environment in which the body exists to determine whether the evaluated body activity is within environmental tolerance. The system monitors both activity and inactivity relative to the environmental representation, and preferably generates state indicia while processing the sensed phenomena.

Turning next to FIGURE 2, there is illustrated a block diagram of the exemplary system of FIGURE 1, which includes processing circuitry 39, indicating means 41, power supply 67, and switch 68, along with sensor 25. Exemplary processing circuitry 39 illustratively includes a processor 47 and buffer amplifiers 43 and 45 that buffer the analog x and y outputs from sensor 25. Exemplary processor 47, which is associated with sensor 25, is capable of processing the sensed accelerative phenomena as a function of at least one accelerative event characteristic and the environmental representation to thereby determine whether an evaluated body movement is within environmental tolerance. Processor 47 also preferably generates state indicia while processing the sensed accelerative phenomena, which may represent the state of the body within the environment over time. Processor 47 is illustratively associated with a crystal oscillator/clock 49, switch (DIP) inputs 51, an analog-digital conversion circuitry 53 and a DSP filter 55 (one conventional processor is available from TEXAS INSTRUMENTS, INC., located in Dallas, Texas, United States of America, namely, Model No. MSP430P325).

Exemplary indicating means 41, in response to direction from processor 47, is operable to accomplish at least one of the following: initiate an alarm event; communicate such state, or tolerance, indicia to a monitoring controller; generate

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statistics; etc. Indicating means 41 may take any number of forms, however, for use in system 11 of the present embodiment, stage 41 is an RF transmitter including RF modulator 61 enabled by processor 47. Exemplary data is presented and modulated at modulator 61, amplified at amplifier 63 and transmitted at

5   antenna 65 (to a remote receiver unit as discussed hereinafter).

According to the present embodiment, power for the various components of system 11 is provided by power supply 67, which illustratively is a 3.6 volt lithium ion battery. Low power management may suitably be under the control of processor 47

10   utilizing exemplary switched/power supply voltage FET switch 68 at sensor 25, which provides power only during sampling cycles, and operates to shut components down during non-use cycles. For instance, processor 47 may be taken off-line when processing is complete, reducing current drain (though alternate approaches and

15   implementations are know in the art and further discussion is beyond the scope of this patent document).

It should be noted that the various circuitry discussed heretofore has been introduced herein for illustrative purposes only. System 11 may be implemented using any suitably arranged

20   computer or other processing system including micro, personal, mini, mainframe or super computers, as well as network combinations of two or more of the same. In point of fact, in

one advantageous embodiment, sensor 25 and processor 47 are not co-located, but rather associated wirelessly. To that end, the principles of the present invention may be implemented in any appropriately arranged device having processing circuitry. Processing circuitry may include one or more conventional

5   processors, programmable logic devices, such as programmable array logic ("PALs") and programmable logic arrays ("PLAs"), digital signal processors ("DSPs"), field programmable gate arrays ("FPGAs"), application specific integrated circuits ("ASICs"), large scale integrated circuits ("LSIs"), very large

10   scale integrated circuits ("VLSIs") or the like, to form the various types of circuitry, processors, controllers or systems described and claimed herein.

Conventional computer system architecture is more fully discussed in THE INDISPENSABLE PC HARDWARE BOOK, by Hans-Peter

15   Messmer, Addison Wesley (2nd ed. 1995) and COMPUTER ORGANIZATION AND ARCHITECTURE, by William Stallings, MacMillan Publishing Co. (3rd ed. 1993); conventional computer, or communications, network design is more fully discussed in DATA NETWORK DESIGN, by Darren L. Spohn, McGraw-Hill, Inc. (1993); conventional data communications

20   is more fully discussed in VOICE AND DATA COMMUNICATIONS HANDBOOK, by Bud Bates and Donald Gregory, McGraw-Hill, Inc. (1996), DATA COMMUNICATIONS PRINCIPLES, by R. D. Gitlin, J. F. Hayes and S. B.

Weinstein, Plenum Press (1992) and THE IRWIN HANDBOOK OF
TELECOMMUNICATIONS, by James Harry Green, Irwin Professional
Publishing (2nd ed. 1992); and conventional circuit design is
more fully discussed in THE ART OF ELECTRONICS, by Paul Horowitz and
Winfield Hill, Cambridge University Press (2nd ed. 1991). Each of

5   the foregoing publications is incorporated herein by reference for
all purposes.

Turning next to FIGURES 3A to 3D, illustrated are exemplary
strip chart records of output of exemplary sensor 25 of FIGURES 1
and 2 taken during illustrative situations. More particularly,

10   FIGURES 3A and 3B illustrate the analog signal at the x and y
outputs of sensor 25 at an active time, namely, during a fall by a
body to the left, and whereas FIGURES 3C and 3D illustrate the
analog signal at the x and y outputs of sensor 25 during a fall by
a body to the right (the dark blocks indicating an alarm

15   condition). As can be seen from the exemplary traces, a fall to
the left and to the right are both distinguishable by the
disruption of a stable position, or normal body movement, by a
concussive force followed by a distinctly different ending stable
position. According to the illustrative embodiment introduced

20   herein, the direction of fall is clear from the position of the
ending trace at the y outputs. If the fall had been more forward
or backward, the x output traces would likewise clearly indicate

the same (this assumes *x* and *y* sensor axes orientation as set forth

in FIGURE 1). Of course, the same *x* and *y* outputs of the sensor 25

may be suitably processed to simply determine position of the body,

for instance, such as when a person is lying down, when a box has

tipped over, etc.

5   Similarly, when system 11 monitors for inactivity, it operates

to identify when the evaluated body activity is relatively small to

inactive as a function of the environmental representation and a

lack to void of accelerative phenomena. Processor 47 counts or

other wise monitors the time period of inactivity. If the body

10   activity level remains relatively small to inactive for a threshold

time period, then processor 47 is operable to generate an alarm

signal. In an advantageous implementation, as the time period

approaches a threshold, processor 47 is also operable to generate

a warning signal. Likewise, if processor 47 determines a relative

15   increase in body activity, it is also operable to restart

(*i.e.*, reset) the time period.

Turning next to FIGURE 4, illustrated is operational flow

diagram of an exemplary method (generally designated 400) of

programming of processor 47 in accordance with a fall detection

20   application of the principles of the present invention. For the

purposes of illustration, concurrent reference is made to

system 11 of FIGURES 1 and 2. It should be noted that this

illustration introduces an exemplary operational method for programming processor 47 for its use as a fall detector, and that suitable alternate embodiments of system 11 for evaluating movement of a body relative to different environments may likewise be implemented in accordance with the principles hereof,

5   such as for relative position, other assistance monitoring, transparent monitoring, tactical maneuver monitoring, etc.

Exemplary method 400 begins and a request for sampling measurements is generated, likely by processor 47 (Step 405), either in response to an executing operations program or upon

10   initiation by a user, possibly remotely from a monitoring controller (discussed with reference to FIGURE 8). Sensor 25 senses x and y acceleration values generating measurement signals at the outputs at sensor 25.

In the present implementation, the measurement signals are

15   converted from analog to digital format and filtered by filter 55 (Step 410; thereby reducing probability that an out-of-tolerance abnormal movement will be determined incorrectly in response to a single sharp impact, such as a collision between mount 17 and a hard surface when sensor 25 is off the body causing a sharp signal

20   spike).

Processor 47 uses direct current (*dc*) voltage components of the outputs from sensor 25 to determine a last stable position of

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the body on which sensor 25 is mounted (Step 415). More particularly, processor 47 repeatedly compares successive input values with immediately preceding input values and, if within tolerance, are added thereto and stored in an accumulator. This is repeated until Z samples have been accumulated and added over

5   some defined period of time (*e.g.*, one second) or until a received input is out of tolerance, in which case the sampling cycle is reinitiated. When Z samples are accumulated and added, the accumulated value is divided by Z to determine a "last stable" static acceleration average value, which is saved and is

10   indicative of the last stable position of the body. Sampling and/or sampling cycle rates may be varied, but, while preferably not continuous due to power consumption concerns, should be substantially continual. It is important to note, therefore, that such characteristics may be statically maintained or

15   dynamically generated.

Processor 47 uses alternating current (*ac*) voltage components of each output from sensor 25 to check against a *G* force threshold value set at DIP switch 51 to see if it exceeds the threshold (Step 420 - thus qualifying as a potential fall impact, in the

20   current example, possibly an intensity in excess of about 2 to 4 *G* depending upon desired sensitivity). According to the present implementation, if three of these dynamic acceleration measurements

are received in excess of the threshold without five intervening measurements that are less than the threshold, the impact detect flag may be set.

Processor 47 determines a fall by testing a post-impact stream of samples against a tolerance (Step 425; for instance, a

5   selected value of the *ac* voltage components, for example a value less than about 2 *G*). Each new sample is tested against the previous sample to see if the position of the body has stabilized. When the position has stabilized to less than the tolerance, *W* samples are averaged to get the new stable static

10   acceleration average value corresponding to the new stable position.

Processor 47, in response to the value corresponding to the new stable position is shifted indicating a change of body position of 45˚ or more from the last stable position, classifies

15   the event as a debilitating fall and alert stage 41 is activated (Step 430). A greater stabilization or post-stabilization sample period may be selected to allow more time for an uninjured user to rise without issuance of an alert.

Processor 47, after setting the last stable position, adds

20   the absolute values of the *x* and *y* last stable positions together, and, then determines whether the body associated with sensor 25 is lying down if the added value exceeds a value

corresponding to 90˙ plus or minus twenty five percent (25%) (Step 435). In such case, after a selected time (for example, four seconds) with repeated like values, the laying down detect flag is set. While this flag is set, any impact that exceeds the *G* force threshold is treated as a debilitating fall (Step 440).

5   The flag is set only as long as the added value continues to indicate that the wearer is lying down.

It should be noted that the foregoing embodiment was introduced for illustrative purposes only and that the present invention broadly introduces systems, as well as methods of

10   operating such systems, that evaluate movement of a body relative to an environment, which in the above-given example is an assistance monitoring environment. An important aspect of the present invention is that processor 47 is operable to process sensed accelerative phenomena as a function of at least one

15   accelerative event characteristic, and that such characteristics will largely be defined by the specific application. Therefore, system 11, and, more particularly, processor 47, generates state indicia relative the environment of interest, and determines whether the evaluated body movement is within tolerance in the

20   context of that environment. For instance, "tolerance" would likely be very different for a monitored body of an elderly person with a heart condition, a toddler, a box in a freight car,

a container of combustible gas, etc.

Processor 47 preferably operates to monitor both activity and inactivity relative to the environment and, more particularly, to identify when the evaluated body activity is relatively small to inactive. Processor 47 may suitably monitor the time period of

5   inactivity. If the body activity level remains relatively small to inactive for a threshold time period, then processor 47 is operable to generate an alarm signal, or, preferably, before the threshold is reached, to generate a warning signal. Again, if processor 47 senses an increase in body activity, it may suitably restart or

10   reset the time period.

Turning next to FIGURE 5, illustrated is a functional block diagram of an alternate sensing system (generally designated 71) that may suitably be associated with processor 47 of FIGURES 1, 2, and 4 in accordance with the principles of the present

15   invention. In this embodiment, components utilizable with system 11 are configured again as a human fall monitor/detector, and any or all of these additional monitoring functions may be employed with system 11, such as inactivity monitoring. For purposes of illustration, concurrent reference is made to processor 47 of

20   FIGURES 2 and 4.

Exemplary sensor 71 includes a respiration module 73, which includes a body contact breath sensor 75 (for example a

volumetric sensor, or a near body breath sensor), low pass filter 77 and amplifier 79 providing output signals indicative of respiration rate and vitality to processor 47. The outputs are processed and, when a dangerous respiratory condition is suggested (generates state indicia relative the environment, and

5   determines whether the evaluated body movement (broadly defined herein to include organic physiologic phenomena) is within environmental tolerance), an identifiable (for example, by signal coding) alarm is sent indicating means 41.

Sensor 71 further includes an ECG module 81, which includes

10   input electrodes 83 and 85 providing heart rate signals to filters 87 and 89. The filtered signals are amplified at amplifier 91 and band pass filtered at filter 93. The output is amplified at 95 for input to processor 47 and processed so that dangerous heart rhythms and events can be detected (generates

15   state indicia relative the environment, and determines whether the evaluated body movement is within environmental tolerance) and an identifiable alarm sent at alert stage 41.

Sensor 71 further includes a panic button module 97 that is operable using a standard user activated switch 99 positioned at

20   housing 17 allowing a user to initiate a call for help. The switch output is input to processor 47 to initiate an identifiable alarm at alert stage 41.

Turning momentarily to FIGURES 6 and 7, illustrated are a perspective view of an exemplary remote receiver unit of the system of this invention and a functional block diagram of the same. In a distributed system in accord with one embodiment of this invention, a remote receiver unit 103 (for example a wall

5   mountable unit) as shown in FIGURES 6 and 7 is provided for receipt of transmissions from sensor 25 and/or system 71. Unit 103 includes a receiver antenna 105, indicator LEDs 107 (including indicators for as many detector functions as are employed in the specific embodiment of the apparatus being

10   monitored, as well as an indicator for unit on/off status), and a user interface input keypad 111 for unit setup, reset and alarm deactivation. Power access 113 is provided at the bottom of the unit.

RF receiver 115 is tuned to receive alarm transmissions from

15   sensor 71 and presents the signal received for processing at processor 117 for alarm identification and appropriate output. Processor 117 also receives inputs from keypad 111 and power switch 119. Non-volatile memory 121 is provided for input of identification of the user and/or of the apparatus being

20   monitored. Audible alarm 123, LED bank 107 and retransmission unit 125 (an autodialer, imbedded digital cellular technology, RF transmitter, an Internet appliance, or the like) are connected to

receive outputs from processor 117.

When a transmission is received, or when battery power at the body mounted apparatus is low, an audible alarm is sounded and the appropriate LED (indicative of the condition causing the alarm, for example a debilitating fall by a user of apparatus 11)

5   is activated. If not disabled by the user at key pad 111 within a short period, processor 117 activates retransmission unit 125 initiating a call for help or other remote notification. Similarly, if processor 117 determines that body activity level has remained relatively small to inactive for near to or at a threshold

10   time period, then processor 117 is operable to respectively generate one of a warning signal and an alarm signal. If not disabled by the user at key pad 111 within a short period, processor 117 again activates retransmission unit 125 initiating a call for help or other remote notification.

15   Operational setup of unit 103 is also accomplished under programming at processor 117 and by sequential operation by a user or technician of keypad 111 and/or power switch 119 as is known (including user ID set, learn mode operations, reset or reprogramming operations, and urgency code operations).

20   Turning next to FIGURE 8, illustrated is an exemplary hybrid wireless/wired network (generally designated 800) that is associated with a remote monitoring controller 805 according to

one embodiment of the present invention. The wireless
network 810 is introduced for illustrative purposes only, and
comprises a plurality of cell sites 821 to 823, each containing
one of the base stations, BS 801, BS 802, or BS 803. Base
stations 801 to 803 are operable to communicate with a plurality

5   of mobile stations (MS) including MS 103 (remote receiver unit
103), and MS 811, MS 812 and MS 814. Mobile stations MS 103, and
MS 811, MS 812 and MS 814, may be any suitable cellular devices,
including conventional cellular telephones, PCS handset devices,
portable computers, metering devices, transceivers, and the like

10   (including, for instance, remote receiver unit 103).

Dotted lines show the approximate boundaries of the cell
sites 821 to 823 in which base stations 801 to 803 are located.
The cell sites are shown approximately circular for the purposes
of illustration and explanation only. It should be clearly

15   understood that the cell sites also may have irregular shapes,
depending on the cell configuration selected and natural and man-
made obstructions.

In one embodiment of the present invention, BS 801, BS 802,
and BS 803 may comprise a base station controller (BSC) and a

20   base transceiver station (BTS). Base station controllers and
base transceiver stations are well known to those skilled in the
art. A base station controller is a device that manages wireless

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communications resources, including the base transceiver station, for specified cells within a wireless communications network. A base transceiver station comprises the RF transceivers, antennas, and other electrical equipment located in each cell site. This equipment may include air conditioning units, heating

5   units, electrical supplies, telephone line interfaces, and RF transmitters and RF receivers, as well as call processing circuitry. For the purpose of simplicity and clarity in explaining the operation of the present invention, the base transceiver station in each of cells 821, 822, and 823 and the

10 base station controller associated with each base transceiver station are collectively represented by BS 801, BS 802 and BS 803, respectively.

BS 801, BS 802 and BS 803 transfer voice and data signals between each other and the public telephone system (not shown)

15 via communications line 831 and mobile switching center (MSC) 840. Mobile switching center 840 is well known to those skilled in the art. Mobile switching center 840 is a switching device that provides services and coordination between the subscribers in a wireless network and external networks 850, such

20 as the Internet, public telephone system, etc. Communications line 831 may be any suitable connection means, including a T1 line, a T3 line, a fiber optic link, a network backbone

connection, and the like. In some embodiments of the present invention, communications line 831 may be several different data links, where each data link couples one of BS 801, BS 802, or BS 803 to MSC 840.

In the exemplary wireless network 800, MS 811 is located in

5   cell site 821 and is in communication with BS 801, MS 103 is located in cell site 822 and is in communication with BS 802, and MS 814 is located in cell site 823 and is in communication with BS 803. MS 812 is also located in cell site 821, close to the edge of cell site 823. The direction arrow proximate MS 812

10   indicates the movement of MS 812 towards cell site 823.

For the purposes of illustration, it is assumed that system 11 is associated with an elderly person whose residence is wirelessly monitored. It is further assumed that sensor 25 is associated with the elderly person and that processor 47 is

15   coupled in MS/remote receiver unit 103, such that sensor 25 and processor 47 are wirelessly associated. System 11 monitors both body activity and inactivity relative to the environmental representation.

System 11 repeatedly senses various physiological phenomena

20   of the elderly person, including accelerative phenomena of his body. Remote processor 47 processes the repeatedly sensed phenomena, and, particularly, the accelerative phenomena of the

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body, as a function of at least one accelerative event characteristic to thereby determine whether the evaluated body movement is within environmental tolerance. Processor 47 advantageously generates state indicia while processing the sensed accelerative phenomena, representing the state of the body

5   within the environment over time (*i.e.*, environmental representation).

Exemplary processor 47 is programmed to distinguish between normal and abnormal accelerative events (*e.g.*, walking, sitting, lying down, etc. versus tripping, falling down, inactivity over

10   time, etc.), and, when an abnormal event is identified, indicates whether the abnormal event is tolerable, or within tolerance. Processor 47 may also suitably be programmed to distinguish other physical characteristics, including temperature, pressure, force, sound, light, relative position (including lying down), and the

15   like.

As processor 47 generates state indicia, which includes tolerance indicia, it uses the same to determine whether the evaluated body movement is within environmental tolerance. Preferably, such tolerance indicia is compared with at least one

20   threshold, likely associated with the accelerative event characteristic. In response to such comparison, processor 47 controls a suitable indicating means to initiate an alarm event

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(locally and via network 810 to monitoring controller 805), to communicate such tolerance indicia to a monitoring controller 805, to generate statistics (locally and via network 810 to monitoring controller 805), or the like.

According to a related advantageous embodiment, such state indicia, and other information is communicated from time to time to monitoring controller 805, from which such information may suitably be perceived. For instance, a technician, medical professional, or relative might wish to review the activities and status of the elderly person. This may easily be facilitated via a centralized data repository accessible via the Internet, or via any other suitably arranged network. While viewing such information, the technician, medical professional, or relative (subscriber 2, generally designated 855) might initiate a diagnostic equipment check, a physiological test, a simple status check, or the like. Similarly, monitoring controller 805, via the network 800, may monitor a "heartbeat" signal generated periodically by MS/remote receiver unit 103, the heartbeat indicating that unit 103 is functional.

FIGURE 9 is a schematic drawing of an alternate advantageous embodiment 900 of the present invention. As shown in FIGURE 9 sensor 25 of embodiment 900 comprises three acceleration measuring devices 910, 920 and 930. The number three is

illustrative only. It is clear that sensor 25 comprises a plurality of acceleration measuring devices and is not limited to a particular number of acceleration measuring devices. Further, sensor 25 as monitored within system 11 may suitably operate to monitor activity and inactivity relative to an environment.

5   Acceleration measuring devices 910, 920 and 930 may each comprises a plural axis measuring device of the type previously described. For convenience, the acceleration measuring devices will be referred to as accelerometers.

          Accelerometers 910, 920 and 930 are each connected to controller 940. Controller 940 comprises processing circuitry 39 (including processor 47), indicating means 41, power supply 67 and switch 68, of the types previously described.

          As shown in FIGURE 9, accelerometer 910, accelerometer 920, and accelerometer 930 are each coupled directly to controller 940. As an electrical circuit connection, it is said that accelerometer 910 and accelerometer 920 are connected to controller 940 in an electrically parallel connection. The connections of accelerometer 910 and accelerometer 920 to controller 940 are not geometrically parallel to each other. In at least one advantageous embodiment of the present invention the connections of accelerometer 910 and accelerometer 920 to controller 940 are located at right angles with respect to each

other. The combination of accelerometer 920 and accelerometer 930

and the combination of accelerometer 910 and accelerometer 930

are similarly arranged.

In one arrangement of this advantageous embodiment of

the present invention, accelerometer 910 is aligned parallel to the

5   x-axis of a three dimensional Cartesian coordinated system and is

capable of measuring accelerations in the x direction.

Accelerometer 920 is aligned parallel to the y-axis and is

capable of measuring accelerations in the y direction.

Accelerometer 930 is aligned parallel to the z-axis and is

10   capable of measuring acceleration in the z direction.

Controller 940 is capable of simultaneously determining the

values of acceleration measured by each of accelerometers 910,

920 and 930. In this manner, controller 940 can determine the

values of acceleration in x, y and z directions. Processor 47 in

15   controller 940 is capable of adding the values of acceleration in

the x, y and z directions to obtain a vector sum (i.e., magnitude

and direction) of the body (not shown) to which accelerometers

910, 920 and 930 are attached. It is noted that although

embodiment 900 has been described for use with a three

20   dimensional Cartesian coordinate system, other three dimensional

coordinate systems may also be used.

For example, FIGURE 10 illustrates a three dimensional

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spherical polar coordinate system having coordinates R, Θ, Φ. FIGURE 10 also illustrates the relationships between a Cartesian coordinate system superimposed on the spherical polar coordinate system. The coordinate R is radial coordinate. The magnitude of R equals the distance from the origin of the coordinate system

5   to the end of a vector that originates at the origin. The coordinate Θ is an angular coordinate that measures the angle between the vector and the z axis. The coordinate Φ is measured in the plane formed by the vector and the z axis. The coordinate Φ is an angular coordinate that measures the angle between the

10   x axis and the projection of the vector on the x-y plane. The coordinate Φ is measured in the x-y plane.

As is shown in FIGURE 10, the relationships between the Cartesian coordinates and the spherical polar coordinates are given by:

$$x = R \sin \Theta \cos \Phi \qquad\qquad (1)$$

$$y = R \sin \Theta \sin \Phi \qquad\qquad (2)$$

$$z = R \cos \Phi \qquad\qquad (3)$$

The values of R, Θ, Φ may be calculated from the values x, y, z by the formulas:

20
$$R = [x^2 + y^2 + z^2]^{1/2} \qquad\qquad (4)$$

$$\Theta = \tan^{-1} [[x^2 + y^2]^{1/2} / z] \qquad\qquad (5)$$

$$\Phi = \tan^{-1} [y / x] \qquad\qquad (6)$$

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As previously mentioned, a plurality of accelerometers may be used. Although each accelerometer 910, 920 and 930 is shown in FIGURE 9 as a single accelerometer, this arrangement is illustrative only. Each accelerometer 920, 920 and 930 may be replaced with two or more accelerometers (not shown). In other

5   words, additional accelerometers (now shown) may be used in addition to accelerometers 910, 920 and 930 shown in FIGURE 9. The additional accelerometers may be oriented in any chosen direction and are not limited to being in the same plane as one of the accelerometers 910, 920 and 930 (or in the same plane as

10   one of the additional accelerometers). In general, accelerometers comprising sensor 25 may be coupled in series, in parallel, or in a combination of series and parallel connections.

Accelerometer 910 is capable of generating analog output voltage signals corresponding to measurements of acceleration in

15   the x direction. Similarly, accelerometer 920 is capable of generating analog output voltage signals corresponding to measurements of acceleration in the y direction and accelerometer 930 is capable of generating analog output voltage signals corresponding to measurements of acceleration in the z direction.

20   The analog output voltage signals of accelerometer 910, 920 and 930 each comprise both an alternating current (ac) voltage component proportional to G forces (i.e., dynamic acceleration

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component related to vibrations of sensor layer 31 of sensor 25)

and a direct current (*dc*) voltage component proportional to an

angle relative to earth (i.e., static acceleration component

related to gravity "g").

The direct current (*dc*) voltage components from

5   accelerometers 910, 920 and 930 (representing static acceleration

due to gravity in their respective x, y and z directions) may be

combined to obtain a value of the acceleration that the body

experiences due to gravity. In general, the vector R represents

the resultant of combining the x, y and z components of

10   acceleration experienced by the body. When a body is at rest

(i.e., dynamic acceleration is zero), the vector R represents the

static acceleration due to gravity.

Because the value of gravity at the earth's surface is

substantially constant for any point on the surface of the earth,

15   the value of gravitational acceleration (obtained by vectorially

summing the gravitational acceleration components) will be the

same for each measurement. That is, the vector sum of each set

of gravitational acceleration components will always give the

same total value of gravitational acceleration experienced by the

20   body as long as the body is at rest (or moving at a constant speed)

relative to an inertial frame of reference. This value is the

gravitational acceleration of approximately thirty two feet per

second per second (32 ft/sec^2) or approximately nine and eight
tenths meters per second per second (9.8 m/sec^2). This value is
customarily referred to as one "g."

Processor 47 in controller 940 is capable of being
programmed to sound an alarm condition when controller 940
receives signals from accelerometers 910, 920 and 930 that exceed
an alarm limit set in accordance with pre-programmed
instructions. In this manner, controller 940 can identify when
the body to which accelerometers 910, 920 and 930 have been
coupled has experienced an acceleration that exceeds a specified
value.

Likewise, processor 47 is capable of being programmed to sound
a warning or alarm condition when controller 940 fails to
receive appreciable signals from accelerometers 910, 920 and 930
that indicate any activity. If processor 47 determines that the
activity level as sensed by accelerometers 910, 920 and 930 has
remained relatively small to inactive for near to or at a threshold
time period, then processor 47 is operable to respectively generate
one of a warning signal and an alarm signal as previously
described.

Processor 47 is capable of combining the alternating current
(ac) voltage components from accelerometers 910, 920 and 930
(representing dynamic acceleration due to external forces in

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their respective x, y and z directions) and the direct current

(*dc*) voltage components from accelerometers 910, 920 and 930

(representing static acceleration due to gravity in their

respective x, y and z directions) to obtain a total value of the

acceleration that the body experiences (due to dynamic

5   acceleration and due to gravity). Because the value of

acceleration due to gravity will always be equal to one "g", any

total value of acceleration that exceeds one "g" will be caused

by the presence of dynamic acceleration on the body.

In an advantageous embodiment of the present invention,

10   processor 47 is programmed to sound an alarm condition when

controller 940 receives signals from accelerometers 910, 920 and

930 that indicate that the total value of acceleration detected

exceeds one "g." In this manner, controller 940 determines that

the body has experienced dynamic acceleration due to external

15   forces because the measured acceleration has exceeded the

"background" acceleration reading that is always present from

gravitational acceleration.

Controller 940 receives the total acceleration signal in the

x direction from accelerometer 910, and the total acceleration

20   signal in the y direction from accelerometer 920, and the total

acceleration signal in the z direction from accelerometer 930.

Controller 940 then combines the total acceleration components to

obtain the total acceleration experienced by the body. Controller 940 then subtracts the value of one "g" from the total acceleration. If the result is greater than zero, then controller 940 has determined that the body has experienced dynamic acceleration due to external forces. Controller 940 then sends

5   an alarm signal in the manner previously described.

In an alternate advantageous embodiment of the present invention, a first plural axis accelerometer 910 and a second plural axis accelerometer 920 are coupled to controller 940 in the orientations shown in FIGURE 11. Accelerometer 910 is

10 aligned as shown in frame 1110. The first axis of accelerometer 910 is aligned parallel to the x axis and the second axis of accelerometer is aligned parallel to the y axis. Accelerometer 920 is aligned as shown in frame 1120. The first axis of accelerometer 920 is aligned parallel to the negative y axis and

15 the second axis of accelerometer 920 is aligned parallel to the z axis.

An advantage is to be gained by aligning accelerometer 910 and accelerometer 920 in this manner. When accelerometer 910 and accelerometer 920 share a common axis it is possible to scale out

20 any inconsistencies between the readings of the two accelerometers. For example, assume that it is known that a force exists in the y direction. Then the force in the y direction

will be the same for both of the two accelerometers. Assume that accelerometer 910 gives a reading of "1.0" for the y direction force and that accelerometer 920 gives a reading of "0.9" for the y direction force. If it is determined that accelerometer 910 has the correct reading, then accelerometer 920 can be

5   "scaled up" (i.e., corrected) to compensate for inconsistencies in the manufacture of accelerometer 920.

FIGURE 12 illustrates an exemplary embodiment of the present invention in which accelerometer 910 and accelerometer 920 are coupled to controller 940. Accelerometer 910 measures

10   accelerations of the body in the positive x direction and in the positive y direction. Accelerometer 920 measures accelerations of the body in the negative y direction and in the positive z direction.

The analog x signal from accelerometer 910 is coupled to an

15   analog digital converter (ADC) 1215 through filter 1205. Similarly, the analog y signal from accelerometer 910 is coupled to ADC 1215 through filter 1210. Filter 1205 and filter 1210 filter out noise artifacts and cancel high frequency elements that may cause analog to digital aliasing. Filter 1205 and

20   filter 1210 may be partially implemented using digital signal processing within controller 940.

ADC 1215 converts analog signals from filter 1205 and filter

1210 to digital signals. ADC 1215 may be external to controller 940 or may be incorporated within controller 940.

Similarly, the analog -y (i.e., negative y) signal from accelerometer 920 is coupled to ADC 1215 through filter 1225. The analog z signal from accelerometer 920 is coupled to ADC 1215

5   through filter 1230. Filter 1225 and filter 1230 also filter out noise artifacts and cancel high frequency elements that may cause analog to digital aliasing. Filter 1225 and filter 1230 may be partially implemented using digital signal processing within controller 940.

10   Controller 940 uses the x, y, z acceleration values to calculate values for the x, y, z distances. This calculation is done by first calculating a time integral of the x, y, z acceleration values to obtain x, y, z velocity values. Then a time integral of the x, y, z velocity values is calculated to

15   obtain the x, y, z distance values. Controller 940 then uses Equations (4), (5), and (6) to calculate the spherical polar (SP) coordinates R, Θ, Φ. Controller 940 then sends the digital form of the R, Θ, Φ coordinates to digital to analog converter (DAC) 1240. DAC 1240 converts the digital form of the R, Θ, Φ

20   coordinates into an analog form. DAC 1240 may be external to controller 940 or may be incorporated within controller 940.

The analog R signal is filtered in filter 1250. The analog

Θ signal is filtered in filter 1260. The analog Φ signal is filtered in filter 1270. The filtered R, Θ, Φ signals are the spherical polar (SP) components of a vector that represents a measurement of the location of the body to which accelerometer 910 and accelerometer 920 are attached.

5   In one advantageous embodiment of the present invention, controller 940 uses indicating means 41 to transmit the SP coordinates to RF receiver 115 and processor 117 (as shown in FIGURE 7). As previously mentioned, RF receiver 115 is tuned to receive transmissions from indicating means 41. As will be

10   more fully described, processor 117 is capable of analyzing the SP coordinate information that it receives from controller 940.

        As time passes, the body to which accelerometer 910 and accelerometer 920 and controller 940 are attached moves (or does not move). Therefore, controller 940 continually sends to

15   processor 117 a stream of SP coordinates that represent the motion of the body. Memory 121 attached to processor 117 contains a library of prerecorded sets of SP coordinates in which each prerecorded set of SP coordinates represents a type of motion.

        For example, a first prerecorded set of SP coordinates

20   could represent inactivity or the absence of motion (i.e., "no motion"). The absence of motion could signify the existence of a problem condition. If the body to which accelerometer 910

and accelerometer 920 and controller 940 is attached is a person, then a "no motion" signal could mean that (1) the person has become unconscious and has ceased moving, or that (2) the sensor device has become detached from the person, or that (3) the sensor device has ceased to function properly, or the like.

5   A second prerecorded set of SP coordinates could represent a successful attempt to change position. A third prerecorded set of SP coordinates could represent an unsuccessful attempt to change position.

           A fourth prerecorded set of SP coordinates could represent

10   the motion of a body moving with a particular type of gait, and especially a gait that is associated with a disability (e.g., limping). The term "moving" generally refers to all types of motion such as walking, running, skipping, jogging, jumping, and other types of motion.

15   A fifth prerecorded set of SP coordinates could represent the motion of a person who is unsteady and is swaying back and forth.

           A sixth prerecorded set of SP coordinates could represent the motion of a person who experiences a "near fall." A near fall occurs when a person loses his or her balance but recovers in

20   time to keep from actually falling. A seventh prerecorded set of SP coordinates could represent the motion of a person who experiences an actual fall.

A series of different types of motion may be recorded in which each type of motion is represented by a prerecorded set of SP coordinates.

Processor 117 analyzes the SP coordinate information that it receives from controller 940 by comparing it with each prerecorded set of SP coordinates stored in memory 121. When processor 117 identifies a match between the measured set of SP coordinates from controller 940 and one of the prerecorded sets of SP coordinates stored in memory 121, then processor 117 generates and sends a message that a match has been found.

The message may be sent by audible alarm 123, LED bank 107 and/or retransmission unit 125. In this manner, controller 940 identifies types of motions that the body experiences including, without limitation, falls, near falls and particular types of gaits of motion.

The ability of processor 117 to detect patterns of motion that typically precede a fall is very useful in preventing falls. For example, an elderly or infirm person who attempts to rise from a bed or chair may be subject to falling. Assume that processor 117 detects a pattern of motion that typically occurs before a fall when a person is attempting to rise from a bed or a chair. Processor 117 can then activate an alarm to alert the person that a fall may be imminent. Upon hearing the alarm, the

person is warned to cease his or her attempt to rise. A nearby care giver may also hear the alarm and come to assist the person before a fall occurs. In this manner serious falls can be prevented.

5   In an alternate advantageous embodiment of the present invention, controller 940 contains the library of prerecorded sets of SP coordinates. In this embodiment, controller 940 performs the analysis of the SP coordinate data. When a match is found, controller 940 generates and sends a message (using indicating means 41) that a match has been found. An alarm may 10   then be sounded in the manner previously described.

FIGURE 13 illustrates a flow diagram showing a first portion of an advantageous embodiment of the method of the present invention. The steps of the first portion of the method are collectively referred to with the reference numeral 1300. At the 15   start of the method, accelerometer 910 and accelerometer 920 measure the x, y, z values of acceleration (step 1310). Controller 940 then calculates the x, y, z distance values (step 1320). Controller 940 then converts the x, y, z distance values to spherical polar (SP) coordinates (step 1330).

20   Processor 117 (or controller 940 in an alternative embodiment) compares a measured set of SP coordinates with each of the plurality of prerecorded sets of SP coordinates that

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represents a type of motion (step 1340). Processor 117 (or controller 940 in an alternative embodiment) identifies a match between the measured set of SP coordinates and one particular prerecorded set of SP coordinates that represents a type of motion (step 1350). Processor 117 (or controller 940 in an

5   alternative embodiment) then sends a message that a match has been found (step 1360).

FIGURE 14 illustrates a flow diagram showing a second portion of an advantageous embodiment of the method of the present invention. The steps of the second portion of the method

10   are collectively referred to with the reference numeral 1400.

The second portion of the method uses the SP coordinate data to calculate a value for a static acceleration vector that represents the value of the earth's gravitational acceleration. When an object falls in a vacuum (i.e., an environment where

15   there is no frictional force due to air resistance) the sum of the components for the static acceleration vector is zero.

When a person loses his or her balance and falls, the measurement of the static acceleration vector that controller 940 records is not zero. The measured value is less than one "g" but

20   is greater than a zero value. The value is greater than zero because the person's muscle tone (due to the slight contraction of skeletal muscles that is always present) operates to slow the

person's body a little bit as the body falls. In some cases, objects may impede the person's fall or the person may reflexively grasp some object to slow the rate of fall.

When the value of the static acceleration vector reaches a value that is less than one "g" but greater than a zero value, that is an indication that controller 940 has experienced a fall. Unlike some types of prior art methods (e.g., tilt switches), this method of detecting a fall does not rely on detecting a change in the angle of orientation of the body. The occurrence of a fall is detected by detecting a reduction in the value of the static acceleration vector to a value that is less than one "g."

If controller 940 was not connected to a person's body during the fall, then the value of the static acceleration vector measured by controller 940 after the fall will instantaneously be equal to one "g." If controller 940 was connected to a person's body during the fall, then the value of the static acceleration vector measured by controller 940 after the fall will rise relatively slowly. This is due to the fact that the person's muscle tone (due to the slight contraction of skeletal muscles that is always present) operates to slow the rise of the value of the static acceleration vector after the fall.

If the value of the static acceleration vector rises at a

rate that is greater than a preselected threshold rate, then it is clear that controller 940 was not connected to a person's body during the fall. If the value of the static acceleration vector rises at a rate that is less than a predetermined threshold rate, then it is clear that controller 940 was connected to a person's

5   body during the fall.

At the start of the second portion of the method of the present invention, controller 940 has converted the x, y, z distance values to spherical polar (SP) coordinates (step 1330). Controller 940 then uses the SP coordinates to calculate the

10   value of the static acceleration vector (step 1410). Controller 940 determines whether the value of the static acceleration vector has reached a value that is less than one "g" (decision step 1420). If not, then controller 940 updates the SP coordinates (step 1430) and control returns to step 1410.

15   If the value of the static acceleration vector has reached a value that is less than one "g," then controller 940 determines the rate at which the value of the static acceleration vector is increasing from the value that is less than one "g" (step 1440). Processor 940 then compares the rate to a preselected threshold

20   rate (decision step 1450). If the rate is greater than the preselected threshold rate, then controller 940 sends a message that controller 940 was not connected to the person's body during

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the fall (step 1470). If the rate is not greater than the preselected threshold rate, then controller 940 sends a message that controller 940 was connected to the person's body during the fall (step 1460). In this manner controller 940 is able to distinguish between a fall of controller 940 alone and a fall of

5   controller 940 while controller 940 was coupled to a person's body.

Relatively rare instances may occur in which controller 940 will require additional information to distinguish between a fall of controller 940 alone and a fall of controller 940 while controller 940 is coupled to a person's body. As previously

10   described, the measured value of acceleration of a falling person is usually less than one "g" but is greater than a zero value. The value is greater than zero because the person's muscle tone (due to the slight contraction of skeletal muscles that is always present) operates to slow the person's body a little bit as the body falls.

15   This is true for normal falling situations.

However, it is not true in the relatively rare cases in which the falling person's body is not in contact with any object. For example, if a person falls off a ladder, then the person's body falls through the atmosphere and does not make contact with any

20   object until impact with the floor or ground. In this type of fall the falling person's muscle tone does not operate to slow the person's body during the fall because the person is not in contact

with an external object.

An alternate advantageous embodiment of the present invention can detect this type of fall. In the alternate embodiment controller 940 detects an additional signal to determine whether controller 940 was coupled to the falling person's body. For example, as previously described, controller 940 comprises processing circuitry 39 that is capable of receiving a signal from respiration module 73. Respiration module 73 is capable of detecting the respiration rate of the falling person.

In an alternate embodiment of the present invention, controller 940 detects a rate at which the value of the static acceleration vector is increasing from a value that is less than one "g". If the detected rate is greater than a preselected threshold rate (usually indicative of a fall of controller 940 not coupled to a body), then controller 940 determines whether a respiration signal was detected within a predetermined time period (e.g., six (6) seconds). If a respiration signal was detected, then processor 940 reports that the fall was a fall of controller 940 connected to a body and not a fall of controller 940 alone.

FIGURE 15 illustrates a flow diagram showing a third portion of an alternate advantageous embodiment of the method of the present invention. The steps of the third portion of the method are collectively referred to with the reference numeral 1500.

At the start of this portion of the method, accelerometer 910 and accelerometer 920 have measured the x, y, z values of acceleration (per step 1310 of FIGURE 13) and controller 940 has calculated the x, y, z distance values (per step 1320 of FIGURE 13).

5   Processor 117 (or controller 940 in an alternative embodiment) determines whether the current x, y, z distance values are the same as the prior x, y, z distance values (step 1510), to thereby determine whether system 11 has remained inactive between measurements. The meaning of the term "same," in the present instance, is determined by the application (i.e., the environment in which the body is monitored) performed by processor 117, and may mean exactly the same or substantially the same depending thereon.

If processor 117 determines that the current x, y, z distance values are the same as the prior x, y, z distance values ("YES" branch of step 1510), then processor 117 increases the counter (step 1520) and determines whether the counter is equal to at least one inactivity threshold value (step 1530). The "counter" may be any means for counting, calculating, enumerating or otherwise computing time or duration during which system 11 remains inactive.

20   Again, "inactivity" is likewise determined by the application performed by processor 117.

If processor 117 determines that the counter is equal to at

least one inactivity threshold value ("YES" branch of step 1530),

then processor 117 reports the occurrence of an inactivity event

(step 1540). Hence, processor 117 has determined that the body

activity level has remained relatively small to inactive for near

to or at a threshold time period. Again, depending upon the

5   application, then processor 117 is operable to respectively

generate one of a warning signal and an alarm signal. System 11

can, for instance, be used to monitor and measure body motions

(accelerations [at variable levels, e.g., .1g, .2g ....], angle

changes [at variable levels, e.g., 15 degrees, 20 degrees.....], or

10   both).

If processor 117 determines that the current x, y, z distance

values are not the same as the prior x, y, z distance values ("NO"

branch of step 1510), then processor 117 resets the counter (step

1550).

15   If processor 117 has reset the counter (step 1550) or

determine that the counter does not equal at least one inactivity

threshold value ("NO" branch of step 1530), then processor 117 sets

the prior x, y, z distance values equal to the current x, y, z

distance values (step 1560). Controller 940 now proceeds to

20   convert the x, y, z distance values to spherical polar (SP)

coordinates (per step 1330 of FIGURE 13).

Although the present invention has been described in detail, those skilled in the art should understand that they can make various changes, substitutions and alterations herein without departing from the spirit and scope of the invention in its broadest form.